THE PHOSPHORESCENT ORGANS OF INSECTS.

BY A. S. PACKARD.

The nature of the phosphorescent organs and their physiology has never seriously engaged the attention of students in this country, and I have thought that some account compiled from the latest and best researches might stimulate inquiry in this country, where fire-flies are universally common.

Phosphorescence is not infrequent in the Protozoa, Cœlenterates, Worms, and has been observed in the bivalve Pholas, in a few abyssal Crustacea, in Myriopods (*Geophilus*), in an Ascidian, Pyrosoma, and in certain deep-sea fishes.

In insects luminosity is mostly confined to a few Coleoptera, and besides the well-known fire-flies, an Indian Buprestid (*Buprestis ocellata*) is said to be phosphorescent; also a Telephorid larva. Other luminous insects are the Poduran *Anurophorus*, *Fulgora*, and certain Diptera (*Culex* and *Tyreophora*).

The seat of the light is the intensely luminous areas situated either in the head (Fulgora), in the abdomen (Lampyridæ), or in the thorax (in a few Elateridæ of the genus Pyrophorus). The luminous or photogenic organ is regarded by Wielowiejsky and also by Emery as morphologically a specialized portion of the fat-body, being a plate consisting of polygonal cells, situated directly under the integument, and supplied with nerves and fine tracheal branches.

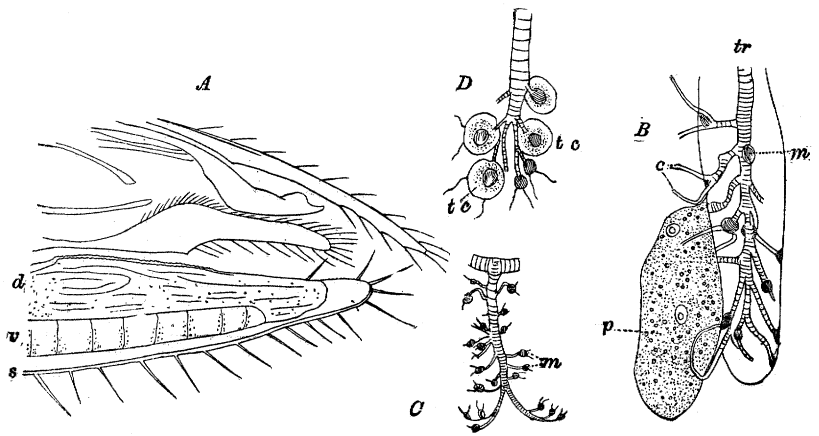

Fig. A. Sagittal section through the hinder end of a male *Luciola*; the organs above the phosphorescent plate only drawn in outline. *s*, integument of the last segment, somewhat removed by the section-knife from the phosphorescent tissues.

d, dorsal layer of the phosphorescent plate penetrated by irregular tracheal branches, and rendered opake by numerous urate concretions imbedded in it; *v*, ventral phosphorescent layer of the plate, with perpendicular tracheal stems whose branches, where they pass into capillaries bear lumps which stain brown with osmic acid. *n*, structurless substance (coagulum?) filling the end of the last ventral segment. B. Isolated portion of the ventral layer of the phosphorescent plate, *tr*. tracheal stem surrounded by a cylindrical lobe; *p*, parenchym-cell attached to the cylinder; *c*, capillary, without the spiral threads; *m*, coagulum stained brown. C. a tracheal stem of the ventral layer: at the fork of the brown-stained capillaries are lumps stained brown with osmic acid. D. a part of C. more highly magnified showing the remains of the tracheal end-cells (*tc*) enveloping the brown lumps (*m*)—after Emery.

In *Luciola* as well as in other fire-flies, including *Pyrophorus*, the phosphorescent organ or plate consists, as first stated by Kölliker, of two layers lying one over the other a dorsal one (*d.*) which is opake, chalky white, and non-photogenic, and a lower one (*v.*), the active photogenic layer, which is transparent. Through the upper or opake layer and on its dorsal surface extend large tracheæ and their horizontal branches, from which arise numerous very fine branches which pass down perpendicularly into the transparent or photogenic layer of the organ. Each tracheal stem, together with its short branches is enveloped by a cylindrical mass of transparent tissue, so that only the short terminal branches or very fine tracheal capillaries project on the upper part of the cylinder. These finest tracheal capillaries are not in *Luciola* filled with air, but with a colorless fluid, as was also found by Wielowiejsky and others in Lampyris.

These transparent cylinders, with the tracheæ within, forming longitudinal axes, resemble lobules. These lobules are so distributed that they appear on a surface section of this plate as numerous round areas in which circular periphery the tracheal capillaries are arranged with the axially disposed tracheal end-cells. These "tracheal end-cells" are only membranous enlargements at the base of the tracheal capillaries (Wielowiejsky). The cylindrical lobules are separated from each other by a substance consisting of abundant large granular cells (parenchym cells) among which project the tracheal capillaries. The cylindrical lobules extend to the hypodermis and come in contact only by their lateral faces with the parenchym.

The structure of the upper opake chalky white layer of the phosphorescent organ is, compared with that of the photogenic lower portion, very simple. In its loose, pappose, mass are no cellular elements, but when treated with different reagents it is seen to be filled with countless urate granules (guanine) swimming in the fluid it contains,

the cell plasma appearing to be dissolved, the cells having lost their cohesion.

In comparing the phosphorescent plate or organ of *Luciola* with that of *Lampyris*, the general structure, including the clear cell elements of the cylindrical lobules, which envelop the perpendicular tracheal twigs and their branches, and also the granular parenchymatous cells are alike in both, though the arrangement and distribution of the elements in *Luciola* is more regular, in *Lampyris* the tracheal stems being irregularly scattered through the parenchym.

Wielowiejsky found in the larval and female *Lampyris* a higher degree of differentiation than in the male, and *Luciola* has a more differentiated photogenic organ than *Lampyris*, as seen in the more regular structure of the lobules.

As regards the light apparatus of *Pyrophorus*, or the cucujo, Heinemann shows and that as in the Lampyridæ, it consists of distinct cells may be regarded as a glandular structure. It is rich in tracheæ and the other parts already described. In still later researches on a Brazilian *Pyrophorus* Wielowiejsky shows that the phosphorescent plate consists of two layers, the upper usually being filled with crystalline urate concretions, and entirely like those of the Lampyridæ, consisting of distinct polygonal cells, among which are numerous tracheal stems, with tænidia, and coursing in different directions, when freshly filled with air, and sending capillaries into the underlying photogenic layer. The latter shows in its structure a striking difference in the cellular arrangement from that of Lampyrids. In the upper or non-photogenic layer are tracheal capillaries which pass down into the underlying cellular plate and which are in the closest possible relations with the single cells, a point overlooked by Heinemann.

PHYSIOLOGY OF THE PHOSPHORESCENCE.

As is well known, the phosphorescence of animals is a scintillating or glowing light emitted by various forms, the greenish light or luminous appearance thus produced being photogenic, *i. e.*, without sensible heat.

Langley rates the light of the firefly at an efficiency of 100 per cent., all its radiations lying within the limits of the visible spectrum. "Langley has shown that while only 2.4 per cent. of luminous waves are contained in the radiation of a gas-flame, only 10 per cent. in that of the electric arc, and only 35 per cent. in that of the sun, the radiation of the fire-fly (*Pyrophorus noctilucus*) consists wholly of visible wave-frequencies." (Barker's Physics, p. 385.)

The spectrum of the light of the cucujo was found by Pasteur to be continuous. (C. R. French Acad. Sc. 1864, ii, p. 509.) A later examination by Aubert and Dubois, showed that the spectrum of the light, examined by the spectroscope is very beautiful, but destitute of dark bands. When, however, the intensity diminishes, the red and orange disappear, and the green and yellow only remain.

Heinemann studied the cucujo at Vera Cruz, Mexico. At night in a dark room it radiates a pale green light which shows a blue tone to the exclusion of any other light. The more gas or lamp light there is present, the more apparent becomes the yellowish green hue, which in clear daylight changes to an almost pure very light yellow with a very slight mixture of green. "In the morning and evening twilight, more constantly and clearly in the former, the cucujo light, at least to my eyes, is an intensely brilliant yellow with a slight mixture of red. In a dark room lighted with a sodium light the yellow tone entirely disappears; on the other hand the blue strikingly increases." As regards the spectrum he found that almost exactly half of the blue end is wanting and that the red part is also a little narrower than in the spectrum of the petroleum flame.

Prof. C. A. Young states that the spectrum given by our common firefly (*Photinus ?*) is perfectly continuous, without trace of lines either bright or dark. "It extends from a little above Fraunhofer's line C, in the scarlet, to about F in the blue, gradually fading out at the extremities. It is noticeable that precisely this portion of the spectrum is composed of rays, which while they more powerfully than any others affect the organs of vision, produce hardly any thermal or actinic effect. In other words, very little of the energy expended in the flash of the fire is wasted. It is quite different with our artificial methods of illumination. In the case of an ordinary gas light the best experiments show that not more than one or two per cent. of the radiant energy consists of *visible rays;* the rest is either invisible heat or actinism; that is to say, over 98 per cent. of the gas is wasted in producing rays that do not help in making objects visible." (Amer. Nat. iii, 1870, p. 615).

Panceri also remarks that while in the spectroscope the light of some Chætopteri, Beroë and Pyrosoma, exhibit one broad band like that given by monochromatic light, that of *Lampyris* and *Luciola* is polychromatic (Amer. Nat. vii, 1873, p. 314.)

The physiology of insect-phosphorescence is thus briefly stated by Lang: "The cells of this luminous organ secrete, under the control of the nervous system, a substance which is burnt during the appearance of the light; this combustion takes place by means of the oxygen con-

veyed to the cells of the luminous body by the tracheæ, which branch profusely in it and break up into capillaries."

Emery states that the males of *Luciola* display their light in two ways. When at night time they are active or flying the light is given out at short and regular intervals, causing the well-known sparkling or scintillating light. If we catch a flying *Luciola* or pull apart one resting in the day time, or cut off its hind body, it gives out a tolerably strong light, though not nearly reaching the intensity of the light-waves of the sparkling light. In this case the light is constant, yet we notice, especially in the wounded insect, that the phosphorescent plate in its whole extent is not luminous, but glows at different places as if phosphorescent clouds passed over it.

It is self-evident that a microscopic observation of the light of the glow-worm or fire-fly is not possible, but an animal while giving out its light, or a separated abdomen, may readily be placed under the microscope and observed under tolerably high powers. By making the experiment in a rather dark room Emery saw clear shining rings on a dark background. "All the rings are not equally lighted. Comparing this with the results of anatomical investigation, and it is seen that the rings of light correspond with the previously described circular tracheal capillaries, *i. e.*, the limits between the tracheal-cell cylinder and the parenchym-cells. The parenchym-cells are never stained of a deep brown; this proves that its plasma may be the seat of the light-producing oxydation. Hence this process of oxydation takes place in the upper surface of the parenchym-cells, but outside of their own substance. The parenchym-cells in reality secrete the luminous matter; this is taken up by the tracheal end-cells and burnt or oxydized by means of the oxygen present in the tracheal capillaries. Such a combustion can only take place when the chitinous membrane of the tracheae is extraordinarily fine and easily penetrable, as is the case in the capillaries of the photogenic plate; therefore the plasma of the tracheal cells only oxydizes at the forking of the terminal tracheal twigs and in the capillaries." (Emery.)

The color of the light of *Luciola* is identical in the two sexes, and the intensity is much the same, though that of the female is more restricted. The rhythm of the flashes of light given out by the male is more rapid, and the flashes briefer, while those of the female are longer, more tremulous and appear at longer intervals.

Emery then asks: What is the use of this luminosity? Is it only to allure the females of *Luciola*, which are so much rarer than the males? Contrary to the general view that it is an alluring act, he thinks that phosphorescence is a means of defense, or a warning or danger-signal

against insectivorous nocturnal animals. If we dissect or crush a *Luciola* it gives out a disagreeable cabbage-like smell, and perhaps this is sufficient to render it inedible to bats or other nocturnal animals. An acrid taste they certainly do not possess.

It has long been known that the eggs of fire-flies, both Lampyridæ and *Pyrophorus*, are luminous. Both Newport and more recently Wielowiejsky attributes the luminosity not to the contents of the egg, but to the portions of the fat-body cells or fluid covering on the outside of the eggs, due to ruptures of the parts within the body of the female during oviposition. The larvæ at different ages are also luminous.

The position of the luminous organs changes with age. In the larvæ of *Pyrophorus* before moulting, according to Dubois, the luminous organs are situated only on the ventral side of the head and prothoracic segment. In larvæ of the second stage there are added three shining spots on each of the first eight abdominal segments, and a single luminous spot on the last segment. These spots are arranged in a linear series and thus form three luminous cords. In the adult beetles there is a luminous spot in the middle of the first abdominal sternite, but the greatest amount of light is produced by the two vesicles on the hinder part of the prothorax, the position of which varies according to the species.

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